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1 Downhole Tools

2

3 This invention relates to downhole tools, and relates
4 more particularly but not exclusively to downhole tools
5 in the form of well-drilling tools which facilitate the
6 drilling of wells which are substantially non-vertical.

7

8 BACKGROUND:

9

10 As oil and gas reserves become scarcer or depleted,
11 methods for more efficient production have to be
12 developed.

13

14 In recent years horizontal drilling has proved to
15 enhance greatly the rate of production from wells
16 producing in tight or depleted formation. Tight
17 formations typically are hydrocarbon-bearing formations
18 with poor permeability, such as the Austin Chalk in the
19 United States and the Danian Chalk in the Danish Sector
20 of the North Sea.

21

22 In these tight formations oil production rates have
23 dropped rapidly when conventional wells have been
24 drilled. This is due to the small section of producing

1 formation open to the well bore.

2

3 However when the well bore has been drilled
4 horizontally through the oil producing zones, the
5 producing section of the hole is greatly extended
6 resulting in dramatic increases in production. This
7 has also proved to be effective in depleted formations
8 which have been produced for some years and have
9 dropped in production output.

10

11 However, horizontal drilling has many inherent
12 difficulties. In broad terms the difficulties include
13 the following factors:

14

15 (i) the rotational torque requirement of the
16 drillstring rises rapidly with increasing hole
17 angle (angular displacement from vertical) and
18 length of the horizontal section,

19

20 (ii) the weight of the drillstring in the vertical
21 section of the hole must push the drillpipe along
22 the horizontal section thereby increasing the
23 fatigue stresses in the drillpipe located on the
24 bend between the two sections,

25

26 and

27

28 (iii) performance of the drillbit is reduced due to
29 both (i) and (ii) above as difficulties in
30 applying weight and torque affect the ROP ("rate
31 of progress" in deepening/lengthening of the
32 well).

33

1 PRIOR ART:

2
3 Conventional stabilisers used in assemblies for
4 horizontal drilling do little to resolve the above
5 problems. Conventional stabilisers have fixed blades
6 which normally are spiralled to distribute well contact
7 area whilst still allowing fluid bypass. Conventional
8 stabilisers also generate quite considerable back
9 torque and resistance to forward motion although they
10 do centralise the drilling assembly and play an
11 important role in directional control of the hole.

12
13 A number of attempts have been made to reduce friction
14 by the development of rolling element stabilisers. A
15 recent one of these stabiliser tools (described in
16 published European Patent Application EP0333450-A1)
17 used freely rotating balls set into the stabiliser
18 blades which addressed points (i) and (ii) above.
19 Initially the tool was well received by the oil
20 industry as there was a real need to resolve the
21 downhole torque problems. Unfortunately the tool
22 proved to have problems with the balls packing off and
23 locking with cutting debris. This considerably reduced
24 the market interest in this tool.

25
26 Another known form of rolling element stabiliser is
27 based on rollers mounted on respective axes which are
28 each parallel to the longitudinal axis of the
29 stabiliser and hence parallel to the longitudinal axis
30 of the drillstring and of the well drilled thereby.
31 Examples of this form of roller stabiliser are
32 described in United States Patent US3907048 and United
33 Kingdom Patent Specification GB271839. The functional
34 effect of this form of roller stabiliser is to reduce
35 rotational friction (by reason of the rolling support

1 of the stabiliser against the bore of the well or well
2 casing), but to have a neutral longitudinal effect (by
3 reason of the parallelism of the roller axes with
4 respect to the longitudinal axis of the stabiliser and
5 the drillstring incorporating the stabiliser).

6
7 A still further form of rolling element stabiliser
8 which purports to reduce both rotational and
9 longitudinal friction is described in United States
10 Patent US1913365. This further form of roller
11 stabiliser essentially comprises a collar which is
12 rotatably mounted on the exterior of a drillstring by
13 two rows of vertical-axis rollers, ie rollers whose
14 respective axes are each parallel to and radially
15 offset from the longitudinal axis of the drillstring.
16 (These vertical-axis rollers are externally spherically
17 shaped, and therefore superficially appear as balls,
18 although they are actually rollers). While the collar
19 is free to rotate on the drillstring (by reason of the
20 rolling support provided by the vertical-axis rollers),
21 the collar is longitudinally retained at a fixed
22 position on the drillstring by end rings clamped to the
23 drillstring. The collar provides longitudinal rolling
24 support for the drillstring by means of an external
25 array of horizontal-axis rollers, ie rollers whose
26 respective axes are each tangential to a circle centred
27 on the longitudinal axis of the drillstring. Thus
28 although this further form of roller stabiliser
29 provides both rotational and longitudinal rolling
30 support for the drillstring, it is to be noted that the
31 purely longitudinal ("vertical") and circumferential
32 ("horizontal") roller axes result in the facts that
33 rotational movement of the drillstring does not result
34 in a net longitudinal force, nor does longitudinal
35 movement of the drillstring result in a net rotational

1 force, ie there is no cross-translation of motion and
2 force between rotational and longitudinal directions.

3
4 United States Patent US4000783 describes a roller
5 reamer, ie a form of annular drilling bit for
6 substantially enlarging the bore of a pilot hole. In
7 this roller reamer, the conical reamers or cutters are
8 rotatably mounted on respective axes that are each
9 triply offset from the longitudinal axis of the
10 drillstring, being offset radially outwards, obliquely
11 (ie conically), and skewed (ie helical) with respect to
12 the drillstring axis. The conical reamers enlarge a
13 previously-drilled hole by gouging away the wall of the
14 pilot hole in an annular region around the tool. It is
15 said that if the reamers are disposed at a skew angle
16 which is greater than the neutral skew angle, the
17 cutters provide a self-advancing action. It is to be
18 noted that the conical reamers or cutters of US4000783
19 provide a purely cutting action, with radial support of
20 this cutting tool being provided by purely static
21 cylindrical shoulders ahead of and behind the cutters
22 (see Fig. 1 of US4000783), a smaller diameter shoulder
23 providing radial support in the pilot hole, and a
24 larger diameter shoulder providing radial support in
25 the enlarged bore. These radial support shoulders are
26 concentric with the longitudinal axis of the tool and
27 of the drillstring.

28
29 OBJECTS OF THE INVENTION:

30
31 It is an object of the invention to provide a downhole
32 tool which provides radial support for a rotatable
33 downhole assembly in a previously drilled hole of
34 substantially uniform diameter, the radial support
35 being provided by a rolling element arrangement which

1 translates rotational movement of the tool to a
2 longitudinal force on the tool.

3
4
5 SUMMARY OF THE INVENTION:
6

7 According to a first aspect of the present invention
8 there is provided a downhole tool for providing radial
9 support for a rotatable downhole assembly within a
10 previously drilled hole of substantially uniform
11 diameter, said tool comprising a central member
12 constructed or adapted to be incorporated in a
13 rotatable downhole assembly for rotation therewith in
14 use of said tool, said central member mounting a
15 plurality of rolling element means in respective
16 positions which are circumferentially distributed
17 around said tool, each said rolling element means being
18 rotatably mounted on a respective axis which is
19 tangential to a notional helix substantially coaxial
20 with the longitudinal axis of said tool about which
21 said tool rotates in use of said tool such that each
22 said respective axis of said rolling element means is
23 skewed with respect to said longitudinal axis, each
24 said rolling element means having a respective
25 periphery which extends to the radially outermost
26 periphery of said tool whereby the radially outermost
27 periphery of said tool provides rolling radial support
28 for said rotatable downhole assembly in use of said
29 tool by means of the peripheries of said rolling
30 element means and the rotation of said rolling element
31 means about their skewed axes translates rotation of
32 said tool in use thereof to a longitudinally-directed
33 force acting through said central member on said
34 downhole assembly.
35

1 Said rotatable downhole assembly may be a drillstring
2 and said notional helix is preferably contra-rotary
3 with respect to the combination of the normal or
4 forward direction of rotation of the drillstring and
5 the direction from said tool towards a drill bit at the
6 downhole end of the drillstring, whereby normal or
7 forward rotation of said drillstring and of the tool
8 incorporated therein results in a longitudinal force
9 tending to propel the drillstring towards the blind end
10 of the bore and ultimately tending to force the drill
11 bit into the geological material to be drilled. Thus
12 if the normal or forward direction of rotation of the
13 drillstring is clockwise as viewed from the surface and
14 looking down into the bore, said notional helix
15 preferably progresses anti-clockwise in a downhole
16 direction therealong whereby the peripheries of said
17 rolling element means, where they extend to the
18 radially outermost periphery of the tool, align with a
19 notional right-hand thread around the outer periphery
20 of said tool.

21
22 Each respective axis of said rolling element means is
23 preferably skewed with respect to the longitudinal axis
24 of the tool at an angle in the range from a very low
25 (but non-zero) angle, up to 45°, and more preferably at
26 an angle in the range from 0.5° to 15°. Said downhole
27 tool may incorporate skew angle variation means
28 operable to make the skew angle controllably variable,
29 and possibly capable of reversing the hand of said
30 notional helix whereby the direction of longitudinal
31 force is reversed without reversing the direction of
32 rotation.

33
34 Said rolling element means are preferably rollers, and
35 the peripheries of said rollers may individually be

1 cylindrical or crowned (ie having relatively larger
2 diameter mid-length portion reducing continuously or
3 discontinuously to a relatively smaller diameter at
4 either end). Said rollers may be individually mounted
5 on a respective axis, or said rollers may be mounted in
6 coaxial groups, preferably such that within a group of
7 rollers, individual rollers of that group are capable
8 of rotating at mutually differing rotational rates.

9
10 Radial force applying means are preferably incorporated
11 in the tool for applying radially outwardly directed
12 radial forces to the rolling element means to increase
13 their traction on the bore. The radial force applying
14 means may be such that the radially outwardly directed
15 radial forces applied to the rolling element means are
16 controllably variable.

17
18 The central member of the tool may be adapted from a
19 conventional fixed-blade stabiliser by reducing the
20 outside diameter slightly below the nominal diameter of
21 the bore of the well in which the tool is to be used,
22 machining or otherwise forming pockets or recesses in
23 the blades, and mounting a roller assembly in each of
24 these pockets or recesses such that the rollers project
25 to define the gauge or radially outermost periphery of
26 the tool at the nominal well bore diameter. Each
27 roller assembly can comprise a single roller or a group
28 of rollers mounted on an axle which is rotatably
29 mounted at each end thereof by a suitable combination
30 of radial bearings and thrust bearings.

31
32 According to a second aspect of the present invention
33 there is provided a rotatable downhole assembly for
34 rotatable operation within a previously drilled hole of
35 substantially uniform diameter, said downhole assembly

1 comprising a downhole motor having a motor housing and
2 a rotatable motor output shaft coupled to a rotatable
3 motor output utilisation means, said downhole assembly
4 further comprising at least one downhole tool according
5 to the first aspect of the present invention, said at
6 least one downhole tool being coupled between said
7 rotatable motor output shaft and said rotatable motor
8 output utilisation means for rotation therewith in
9 operation of said assembly to provide radial support
10 therefor and to translate such rotation to a
11 longitudinally-directed force acting through said motor
12 output utilisation means.

13
14 Said downhole assembly may comprise a plurality of such
15 downhole tools, each according to the first aspect of
16 the present invention, and each being coupled between
17 said rotatable motor output shaft and said rotatable
18 motor output utilisation means, said tools being
19 optionally mutually separated by one or more drill
20 collars or other suitable longitudinal spacer means
21 serving in operation of said assembly to convey torque,
22 rotation, and longitudinal forces between parts of said
23 assembly mutually separated by such spacer means.

24
25 Said rotatable motor output utilisation means may
26 comprise a drill bit, said at least one downhole tool
27 comprised in said downhole assembly being formed
28 dynamically to increase the effective weight-on-bit
29 during normally directed rotation of said drill bit by
30 said downhole motor.

31
32 Said motor housing is preferably coupled to
33 countertorque means for reacting motor torque output by
34 said motor output shaft, said countertorque means
35 rotationally constraining said motor housing with

1 respect to said previously drilled hole. Said
2 countertorque means may provide a rotational braking
3 effect while allowing relative freedom of movement in a
4 longitudinal direction, preferably by forming said
5 countertorque means with a peripheral array of
6 hole-contacting rotatable rollers having their axes of
7 rotation substantially tangential to notional circles
8 substantially coaxial with the longitudinal axis of
9 said downhole assembly. Alternatively, said
10 countertorque means may comprise a further downhole
11 tool in accordance with the first aspect of the present
12 invention, the notional helix of said further downhole
13 tool being oppositely handed with respect to the
14 notional helix of said at least one downhole tool
15 coupled between said rotatable motor output shaft and
16 said rotatable motor output utilisation means whereby
17 relative contrarotation of said motor housing with
18 respect to said motor output shaft results in commonly
19 directed longitudinal forces at said at least one and
20 further downhole tools comprised in said downhole
21 assembly.

22
23 The motor of said downhole assembly may be a hydraulic
24 motor supplied in operation thereof with pressurised
25 fluid by way of tubing which may be flexible (ie,
26 tubing which is known in the art as "coiled tubing"),
27 said downhole assembly preferably being coupled to said
28 tubing by way of a swivel coupling which is preferably
29 substantially fluid-tight.

30
31 Said downhole assembly may have major components and
32 sub-assemblies thereof longitudinally coupled by one or
33 more couplings transmissive of torque and longitudinal
34 forces but yieldable about axes transverse to the
35 longitudinal axis whereby the downhole assembly may

1 conform to bent holes.

2

3 DESCRIPTION OF EXEMPLARY EMBODIMENTS:

4

5 Embodiments of the present invention will now be
6 described by way of example, with reference to the
7 accompanying drawings wherein:-

8

9 Fig. 1 is an elevational view of a first
10 embodiment of the present invention;
11 Fig. 2 is an elevational view of a form of roller
12 suitable for use with the present invention;
13 Fig. 3 is an elevational view of another form of
14 roller suitable for use with the present
15 invention;
16 Figs. 4 and 5 are respectively an elevational view
17 and a plan view of a second embodiment of the
18 present invention;
19 Fig. 6 and 7 are respectively an elevational view
20 and a plan view of a third embodiment of the
21 present invention;
22 Fig. 8 is an elevational view of a fourth
23 embodiment of the present invention;
24 Fig. 9 is a schematic longitudinal elevation of a
25 fifth embodiment of the present invention;
26 Fig. 10 is a schematic longitudinal elevation of a
27 sixth embodiment of the present invention;
28 Fig. 11 is a schematic longitudinal elevation of a
29 seventh embodiment of the present invention;
30 Figs 12 and 13 are respectively an elevational
31 view and a plan view of an eighth embodiment of
32 the present invention;
33 Fig. 14 is a schematic longitudinal elevation of a
34 ninth embodiment of the present invention;
35 Figs 15 and 16 are elevational views of a tenth

1 embodiment of the present invention, taken in
2 mutually orthogonal directions;
3 Fig. 17 is a perspective view of an eleventh
4 embodiment of the present invention;
5 Figs 18 and 19 are respectively schematic
6 elevational and plan views of a twelfth embodiment
7 of the present invention; and
8 Figs 20 and 21 are respectively schematic
9 elevational and plan views of a thirteenth
10 embodiment of the present invention.

11

12 Referring first to Fig. 1, a first embodiment of
13 downhole tool 10 in accordance with the present
14 invention comprises a central member 12 whose form is
15 generally that of a conventional fixed-blade
16 stabiliser. The central member 12 comprises a hollow
17 shaft 14 having a standard A.P.I. (American Petroleum
18 Institute) box connector 16 at the upper end and a
19 standard A.P.I. pin connector 18 at the lower end for
20 connection of the tool 10 in a conventional drillstring
21 (not shown).

22

23 The shaft 14 of the central member 12 has three spiral
24 blades 20 formed integrally thereon, each of the blades
25 20 describing a clockwise helix. The radially outer
26 edge 22 of each blade 20 has a radius (measured from
27 the longitudinal axis of the tool 10) which is slightly
28 less than the nominal gauge of the tool 10, ie a radius
29 slightly less than the radius of the bore in which the
30 tool 10 is designed to be used.

31

32 Three pockets 24 are cut through each outer edge 22 and
33 into the bodies of the blades 20. Within each pocket
34 24, a roller 26 is rotatably mounted on a respective
35 axle 28 such that part of the outer periphery of each

1 roller 26 radially extends beyond the respective outer
2 edge 22 of the respective blade 20 to define the
3 radially outermost periphery of the tool 10.

4
5 Each of the roller axles 28 is skewed with respect to
6 the longitudinal axis of the tool 10 about which the
7 tool 10 rotates in use thereof, ie each roller axle 28
8 is tangential to a respective notional helix
9 substantially coaxial with the longitudinal axis of the
10 tool 10 and spiralling anti-clockwise in a downward
11 direction (ie each notional helix is of opposite hand
12 to the illustrated helical shape of the blades 20). As
13 shown in Fig. 1, the roller axles 28 extend
14 transversely of the blades 20, and therefore a notional
15 point on the outer periphery of any one of the rollers
16 26 would, as the roller rotated and where the notional
17 point was proud of the respective blade 20, describe a
18 path generally along the line of the outer edge 22 of
19 that blade, ie a notional right-hand thread around the
20 outer periphery of the tool 10.

21
22 The result of this roller mounting configuration is
23 that the array of rollers 26 provides rolling support
24 for the tool 10, and hence for the drillstring in which
25 it is incorporated, by bearing against the
26 substantially uniform diameter bore of the hole drilled
27 by the drilling bit above which the tool 20 is fitted,
28 while simultaneously reacting with the bore to
29 translate the clockwise rotation of the tool 10 (as
30 viewed from above and looking downhole) into a
31 downwardly-directed longitudinal force by reason of the
32 skewing of each roller 26 as described above. Thus, in
33 normal drilling operations while the drillstring is
34 rotating clockwise (as viewed from above and looking
35 downhole), the tool 10 will cause the drillstring to

1 "walk" downhole, so enhancing the pressure on the drill
2 bit and improving ROP. This beneficial and desirable
3 effect is enhanced by increased side-loading on the
4 tool 10, such as will be experienced as the bore
5 increasingly deviates from vertical, to reach a maximum
6 in horizontal stretches of the bore (where the weight
7 of the horizontal sections of the drillstring is
8 ineffective to push the drill bit forwards). It is
9 also in such deviated and ultimately horizontal
10 stretches of the bore that low-friction radial support
11 of the drillstring is most required, and is provided by
12 the tool 10 simultaneously with the above-described
13 tractive effort.

14

15 The skew angle at which each of the rollers 26 is
16 mounted on the tool 10 may be any non-zero angle from a
17 very small angle (eg, under 1°) up to about 45° (or
18 greater in appropriate circumstances), and is
19 preferably in the range 0.5°- 15°. The skew angle is
20 preferably selected to give a greater rate of
21 theoretical progress (as denoted by the pitch of the
22 above-mentioned notional thread) than the maximum ROP
23 practically achievable by the drill bit, such that
24 there is always a forward (downhole-directed) tractive
25 effort during forward (clockwise) rotation of the
26 drillstring.

27

28 As is clearly shown in Fig. 1, the rollers 26 are
29 angularly distributed around the periphery of the tool
30 10, thus tending to give a relatively uniform loading
31 on the bore of the well in which the tool 10 is being
32 used. It should be noted that the well bore will
33 necessarily be of a substantially uniform diameter in
34 those parts of the bore in which the tool 10 is used,
35 since the tool 10 is devoid of any cutting, chiselling,

1 reaming, or gouging action. Indeed, any such reaming
2 action is undesirable, and is avoided at least partly
3 by the suitable distribution of the rollers 26 and by
4 the form of their peripheries (of which more details
5 are given below).
6

7 Reversal of the direction of rotation of the
8 drillstring (ie rotation of the drillstring in an
9 anti-clockwise direction as viewed from above and
10 looking downhole) will result in concomitant reversal
11 of the above-described longitudinal force to give an
12 uphole-directed tractive effort which will assist in
13 withdrawal of the drillstring from the well.
14 Nevertheless, the desirable low-friction radial support
15 of the drillstring provided by the tool 10 incorporated
16 therein will be maintained even during such reverse
17 rotation.
18

19 Referring now to Figs. 2 and 3, these show two forms of
20 roller suitable for use in the present invention.
21 In Fig. 2, the roller 200 is a crown roller having a
22 (schematically depicted) rotation axis 202. The
23 diameter of the roller periphery 204 varies smoothly
24 (continuously) from a maximum at the mid-length to a
25 somewhat lesser diameter at each end. The length of
26 the roller 200 (as measured along its rotation axis
27 202) is similar to the maximum diameter of its
28 periphery 204. Crowning of the roller periphery 204
29 enhances distribution of the loading on the roller 200
30 in its contact with the bore of the well, as does
31 avoidance of discontinuous changes in peripheral
32 diameter.
33

34 In Fig. 3, the roller 300 is a barrel roller having a
35 schematically depicted rotation axis 302. The roller

1 periphery 304 has a mid-length section 306 of
2 substantially constant diameter which merges into
3 conically tapering sections 308 at each end of the
4 roller 300. The length of the roller 300 (as measured
5 along its rotation axis 302) is a small multiple of the
6 maximum diameter of its periphery 304 (ie the diameter
7 of the mid-length periphery section 306).
8

9 Referring now to Figs. 4 and 5, these respectively
10 illustrate an elevation and a plan view of a second
11 embodiment of downhole tool 410 in accordance with the
12 present invention. The tool 410 is generally similar
13 to the tool 10 previously described with reference to
14 Fig. 1, and accordingly those parts of the tool 410
15 which are identical or equivalent to parts of the tool
16 10 will be given the same reference numerals, but
17 preceded by a "4" (ie the Fig. 1 reference numerals
18 plus 400). The following description will concentrate
19 principally on those parts of the tool 410 which differ
20 from the tool 10, and for a detailed description of
21 parts of the tool 410 not described below, reference
22 should be made to the relevant parts of the foregoing
23 description of the tool 10.
24

25 Apart from some differences in dimensional proportions
26 (principally an increase in relative lengths), the
27 major difference in the tool 410 with respect to the
28 tool 10 lies in a substantial increase in the numbers
29 of rollers mounted in the periphery of the tool 410.
30 As shown in Fig. 4, a correspondingly increased number
31 of pockets 424 is cut through each outer edge 422 and
32 into the bodies of the blades 420. The rollers mounted
33 one in each of the pockets 424 are omitted from Figs. 4
34 and 5, but are similar to the rollers 26 in the tool 10
35 as shown in Fig. 1; in particular the skewing of the

1 roller axles in the tool 410 is essentially the same as
2 in the tool 10. The performance and functions of the
3 tool 410 are as described above in respect of the tool
4 10, save for the effects of the increased number of
5 rollers.

6
7 Referring now to Figs. 6 and 7, these respectively
8 illustrate an elevation and a plan view of a third
9 embodiment of downhole tool 510 in accordance with the
10 present invention. The tool 510 is similar to the tool
11 410 described above with reference to Figs. 4 and 5,
12 and accordingly those parts of the tool 510 which are
13 identical or equivalent to parts of the tool 410 will
14 be given the same reference numerals, but with the
15 leading "4" substituted by a "5". The following
16 description will concentrate principally on those parts
17 of the tool 510 which differ from the tool 410, and for
18 a detailed description of parts of the tool 510 not
19 described below, reference should be made to the
20 relevant parts of the foregoing descriptions of the
21 tools 410 and 10.

22
23 The major difference in the tool 510 with respect to
24 the tool 410 lies in the replacement of the crown
25 rollers of the second embodiment with a much increased
26 number of needle rollers. Accordingly, the
27 approximately circular roller pockets 424 of the second
28 embodiment are replaced by a correspondingly greater
29 number of relatively narrow roller pockets 524 cut
30 through each outer edge 522 and into the bodies of the
31 blades 520. The needle rollers mounted one in each of
32 the pockets 524 are omitted from Figs. 6 and 7, but are
33 mounted with their rotation axis each transverse the
34 respective blade 520. Because of the relatively small
35 diameter and relatively great length/diameter ratio of

1 the needle rollers of the third embodiment, it is
2 preferred to mount the needle rollers each in a
3 suitably re-entrant pocket, preferably lined with a
4 suitable bearing material, to retain the rollers in the
5 tool 510, rather than to mount the rollers on
6 individual axles as in the other embodiments of the
7 present invention. Nevertheless, the rotational
8 alignment of each of the needle rollers of the third
9 embodiment is essentially the same as for the rollers
10 of the other embodiments. The performance and function
11 of the tool 510 is the same described above in respect
12 of the tools 10 and 410, save for the effects of the
13 number, size, and shape of the needle rollers.

14

15 Turning now to Fig. 8, this illustrates a downhole tool
16 610 which is a fourth embodiment of the present
17 invention. The tool 610 comprises a central member 612
18 which has the form of a fixed-blade stabiliser with a
19 hollow shaft 614 having a standard A.P.I. box connector
20 616 at the upper end, and a standard A.P.I. pin
21 connector 618 at the lower end for connection of the
22 tool 610 in a conventional drillstring (not shown).

23

24 The shaft 614 of the central member 612 has three
25 spiral blades 620 formed integrally thereon, each of
26 the blades 620 describing an anti-clockwise helix or
27 left-handed spiral. (This is in contrast to the blades
28 20 in the tool 10, which each describe a clockwise
29 helix or right-handed spiral). The radially outer edge
30 622 of each blade 620 has a radius (measured from the
31 longitudinal axis of the tool 610) which is slightly
32 less than the nominal gauge of the tool 610, ie a
33 radius slightly less than the radius of the bore in
34 which the tool 610 is designed to be used.

35

1 A recess 624 is cut from the outer edge 622 and into
2 the body of each blade 620. Within each pocket 624, a
3 roller assembly 626 is rotatably mounted on a
4 respective axle 628 such that part of the outer
5 periphery of each roller assembly 626 radially extends
6 beyond the respective outer edge 622 of the respective
7 blade 620 to define the radially outermost periphery of
8 the tool 610.

9
10 Each of the roller assembly axles 628 is skewed with
11 respect to the longitudinal axis of the tool 610 about
12 which the tool 610 rotates in use thereof, ie each
13 roller assembly axle 628 is tangential to a respective
14 notional helix substantially coaxial with the
15 longitudinal axis of the tool 610 and spiralling
16 anti-clockwise in a downward direction (ie each
17 notional helix is of the same hand as the illustrated
18 helical shape of the blades 620, and in a preferred
19 form of the fourth embodiment, each notional helix is
20 substantially coincident with the centre-line of the
21 respective helical blade 620). As shown in Fig. 8, the
22 roller assembly axles 628 extend longitudinally of the
23 blades 620, and therefore a notional point in the outer
24 periphery of any one of the roller assemblies 626
25 would, as the roller assembly rotated and where the
26 notional point was proud of the respective blade 620,
27 describe a path generally transverse the outer edge 622
28 of that blade, ie a notional right-hand thread around
29 the outer periphery of the tool 610.

30

31 Each of the roller assemblies 626 comprises a group of
32 rollers 630 coaxially mounted side-by-side along the
33 respective axle 628 such that each roller 630 can
34 individually rotate independently of its neighbours,
35 thereby permitting traction without slippage due to

1 differential rotational velocities along the roller
2 assembly 626. The overall profile of each roller
3 assembly 626 is ellipsoidal or hyperboloidal to suit
4 the circumferential curvature of the well bore in which
5 the tool 610 is used, in conjunction with the selected
6 skew angle of the axles 628 (this skew angle preferably
7 being in the range 0.5° - 15° , and possibly up to about
8 45°). End sections 632 of the roller assemblies 626
9 may be peripherally faced with wear-resisting inserts
10 634 (eg of tungsten carbide).
11

12 Opposite ends of each roller assembly axle 628 are
13 housed in uncutaway portions of the body of the
14 respective blade 620 wherein radial loading on the
15 respective axle 628 is sustained by radial bearings,
16 and axial loading is sustained by suitable axial
17 bearings. In order to give access to a longitudinal
18 axle-accommodating bore through the body of each blade
19 620 from the lower end face thereof, the shaft 614 of
20 the central member 612 is made in two parts mutually
21 connected by a standard A.P.I. pin and box connector
22 636 (shown in ghost outline) joining the two shaft
23 parts immediately below the lower end faces of the
24 blades 620.
25

26 Each roller assembly axle bearing arrangement may be
27 provided with a pressure-compensated grease reservoir
28 638 (only one being visible in Fig. 8) to provide
29 lubrication therefor in a manner which inhibits the
30 ingress of drilling debris and other foreign material.
31

32 The portions of the blade edges 622 not cut away to
33 form the roller assembly recesses 624 may be faced with
34 wear-resisting inserts 640 (eg of tungsten carbide) to
35 mitigate the effects of unintended direct contact of

1 the blade edges 622 with the well bore, such as may
2 occur in the event of excessive wear of the roller
3 assemblies 626 or collapse of their axles 628 or of
4 their bearings.

5

6 Normal operation of the downhole tool 610 is as
7 described above in respect of the downhole tool 10.

8

9 Referring now to Fig. 9, this schematically depicts a
10 longitudinal elevation of a downhole assembly 700 in
11 accordance with the present invention. The assembly
12 700 comprises a downhole motor 702 having a motor
13 housing 704 and a rotatable motor output shaft 706.
14 The motor shaft 706 is coupled through a first downhole
15 tool 708, a drill collar 710 (only the ends of which
16 are shown), and a second downhole tool 712 to a drill
17 bit 714.

18

19 Each of the tools 708 and 712 is similar to the
20 previously described downhole tools 10, 410, & 610 in
21 having three skew-axis rollers mounted around its
22 periphery to provide radial support for the downhole
23 assembly 700, and to translate rotary motion during use
24 of the assembly 700 into a longitudinal force acting on
25 the drill bit 714 to increase its effective weight-on-
26 bit.

27

28 The motor housing 704 is coupled to and radially
29 supported by a roller assembly 716 having a peripheral
30 array of rollers each having their rotation axis
31 tangential to a notional circle coaxial with the
32 longitudinal axis of the assembly 700 (equivalent to
33 one of the previously described downhole tools but with
34 a skew angle of 90°, or somewhat like the outer part of
35 the "antifriction bearing" of US1913365). The effect

1 of the roller assembly 716 is to provide countertorque
2 for the motor 702, ie, to inhibit anticlockwise
3 rotation of the motor housing 704 while the motor
4 output shaft 706 is being driven clockwise by operation
5 of the motor 702. This countertorque is achieved by
6 the circumferential alignment of the roller axes in the
7 roller assembly 716, which prevents free rotation of
8 the roller assembly 716 (though some limited rotation
9 may take place due to slippage), though longitudinal
10 movement of the roller assembly 716, and hence of the
11 downhole assembly 700, can take place relatively
12 freely.

13

14 The motor 702 is a hydraulic motor of the Moineau type
15 which is fed with pressurised hydraulic fluid through a
16 flexible tube 718 of the type known as "coiled tubing".
17 The tube 718 is linked to the downhole assembly 700
18 through a fluid-tight rotary swivel 720 to prevent
19 rotation of the motor casing 704 (due to slippage of
20 the roller assembly 716) inducing undesirable
21 distortions in the tube 718.

22

23 Turning now to Fig. 10, this shows a downhole assembly
24 800 which is similar in many aspects to the above-
25 described assembly 700, but which differs in one
26 substantive respect (detailed below). Those parts of
27 the assembly 800 which are identical to or equivalent
28 to like parts of the assembly 700 are given the same
29 reference numeral, but with the leading "7" substituted
30 by an "8". Therefore, for a full description of any
31 part of the assembly 800 not detailed below, reference
32 should be made to the appropriate part of the foregoing
33 description of the assembly 700.

34

35 The substantive difference in the downhole assembly 800

1 with respect to the downhole assembly 700 consists in
2 replacing the roller assembly 716 with a further
3 downhole tool 830 which is essentially similar to the
4 downhole tools 808 and 812, except that the hand of the
5 notional helix is reversed, ie each roller 832 is
6 mounted on a respective roller axle 834 which is
7 tangential to a notional helix substantially coaxial
8 with the longitudinal axis of the tool 830 and
9 spiralling clockwise ("right hand") in a downward
10 direction (right to left as viewed in Fig. 10). The
11 effect of this roller pitch reversal in the tool 830
12 with respect to the anticlockwise ("left hand") roller
13 pitch in the tools 808 and 812 is that as the motor
14 housing 804 contrarotates (anticlockwise as viewed from
15 above) as a consequence of reacting the clockwise
16 output torque of the motor output shaft 806, the tool
17 830 produces a longitudinal force acting in a downward
18 direction (right to left as viewed in Fig. 10), thus
19 dynamically adding to the effective "weight" on the
20 drill bit 814.

21
22 The tool 830 is preferably set up and adjusted so that
23 the tool 830 is less susceptible to longitudinal
24 slippage than the tools 808 and 812. As well as the
25 adoption of slippage-reducing measures such as
26 providing the rollers 832 with high-grip surfaces, such
27 an objective can be attained by additionally or
28 alternatively urging the rollers 832 radially outwards
29 of the tool 830, eg by mounting the roller axles 834 on
30 springs (not shown) arranged to force the axles 834,
31 and the rollers 832 mounted thereon, radially outwards
32 of the tool 830; alternatively the axles 834 could be
33 mounted on pressurisable actuators (not shown), eg
34 hydraulic piston and cylinder assemblies, disposed to
35 force the axles 834 and the rollers 832 thereon.

1 radially outwards of the tool 830 when suitably
2 pressurised. Spring enhancement of roller traction
3 forces (ie radial outward forces) has the advantage of
4 being continuous and automatic, while hydraulic or
5 other pressure enhancement of roller traction forces is
6 capable of being suitably controlled in respect of
7 factors such as timing and magnitude, thus enabling
8 better performance of the downhole assembly 800 in
9 operation thereof.

10
11 Dominance by the tool 830 over the tools 808 and 812 in
12 terms of their respective contributions to the
13 production of longitudinal forces in a common downhole
14 direction can be further assured by making the tools
15 808 and 812 undergauge, ie by arranging their roller
16 axle locations and/or the roller diameters to make the
17 overall outside diameter of the tools 808 and 812
18 marginally less than the bore of the previously drilled
19 hole in which the downhole assembly 800 is operated.

20
21 The tools 808 and 812 not only function to provide a
22 dynamically increased weight-on-bit (as previously
23 detailed), the tools 808 and 812 additionally function
24 as stabilisers, ie they function to provide radial
25 support for the parts of the downhole assembly 800
26 between and including the motor shaft 806 and the drill
27 bit 814, allowing relatively low-friction rotation of
28 these components by reason of the rollers forming the
29 peripheries of the tools 808 and 812. Thus the dual-
30 function tools 808 and 812 may conveniently be termed
31 "traction stabilisers". Similarly, the tool 830 can be
32 termed the "dominating stabiliser".

33
34 In the Fig. 10 arrangement, the negative effects of the
35 reaction torque of the motor 802 will be utilized to

1 positive effect, providing an additional thrust or
2 motive force to that of the traction stabilisers 808
3 and 812.

4
5 As the motor output shaft 806 rotates providing torque
6 to the drill bit 814, the traction stabilizers 808 and
7 812 provide forward thrust due to their ability to
8 "walk" into the wellbore under the influence of the
9 left-hand flutes incorporating the tractive rolling
10 elements. The pitch of the left-hand helix will be
11 constructed in such a way that the traction stabilizers
12 808 and 812 will attempt to "walk" into the wellbore
13 faster than either the coil-tubing 818 can be unreeled
14 into the wellbore, or the drill bit 814 can cut into
15 fresh formation. This situation creates slippage
16 between the traction stabilizers 808, 812 and the
17 wellbore.

18
19 However, although the motor 802 will provide nominally
20 constant rpm to the drilling assembly, the fact that
21 the dominating stabilizer 830 is configured to reduce
22 the opportunity for slippage will cause a change in the
23 relative rotational speeds of the motor rotor 806 and
24 motor casing 804 with respect to the wellbore. It is
25 envisaged that the motor casing 804 will slow down in
26 direct proportion to the reduction in forward motion
27 from the calculated on the basis of the helix angle.
28 The reduced rotational speed of the motor casing 804
29 will be compensated by an increase in the rotational
30 speed of the rotor 806, thereby providing the same
31 thrust to the drillbit 814, irrespective of the
32 rotational fluctuations of the assembly 800. In short,
33 this system will provide automatic compensation of the
34 weight-on-bit longitudinal thrust provided at the
35 drillbit 814.

1 To illustrate more fully and clearly the mechanism of
2 operation the following numerical illustration is shown
3 by way of example, although the figures given are not
4 mandatory in every case.

5
6 Given that the best operation of typical coil-tubing is
7 RIH ("run into hole") @ 1000 ft/hr it is imperative
8 that the motive force provided by the traction
9 stabilizers is configured for significantly more
10 longitudinal progress than this.

11

12 $1000 \text{ ft/hr} = 0.28 \text{ ft/sec}$

13 $5 \text{ miles/hr} = 7.33 \text{ ft/sec}$

14

15 In effect this means that the traction stabilizers
16 would "walk" downhole at 7.33 ft/sec but are
17 constrained to 0.28 ft/sec, roughly 4% of their
18 capability. The remaining capability must therefore be
19 dissipated as slippage between the traction stabilizers
20 and the wall of the wellbore.

21

22 If the motor 802 is designed to operate at 400 rpm, and
23 uses 300 rpm to drive the rotor 806 (and therefore the
24 traction stabilizers 808 and 812) the remaining 100 rpm
25 would be seen at the motor casing/dominating stabilizer
26 interface.

27

28 Given that the dominating stabilizer 830 will not slip,
29 the rotational speed of the motor casing 804 will
30 reduce from 100 rpm to 4 rpm, to compensate for the
31 reduction in forward motion of the stabilizers 808 and
32 812, in direct proportion. Equally, the remaining
33 96 rpm will now transfer to the motor's rotor 806, and
34 its shaft speed can be transferred back and forth
35 between the rotor 806 and the casing 804 to provide a

1 constant thrust to the drill bit 814.

2

3 It is possible that due to the very shallow angles
4 involved in the setting of the left-hand stabilizers
5 808 and 812 that a mechanism can be developed which
6 inverts the orientation of the flutes and hence the
7 helix angle of the rollers such that for a continued
8 input rotation the downhole assembly would now "walk"
9 back out of the hole.

10

11 Referring now to Fig. 11, this schematically
12 illustrates a downhole assembly 900 which is a
13 modification of the assembly 800 described above with
14 reference to Fig. 10. The assembly 900 is configured
15 to function as a pipe crawler or pipe tug assembly
16 capable of pulling pipes, cables, inspection and
17 testing equipment, and the like along tunnels,
18 conduits, and similar underground passages that have
19 been formed prior to the passage of the assembly 900.
20 Those parts of the assembly 900 which correspond to
21 equivalent or analogous parts of the assembly 800 are
22 given the same reference numeral, but with the leading
23 "8" replaced by a "9"; reference should be made to the
24 appropriate parts of the preceding description for
25 details of any part of the assembly 900 not described
26 below.

27

28 In the assembly 900, items forward (downhole or
29 leftwards as viewed in Fig. 11) of the tool/stabilizer
30 908 are removed and replaced by a bull-nose 940. The
31 rear or uphole end of the assembly 900 is fitted with a
32 cable attachment 950 to which (for example) a cable 960
33 may be attached to be dragged through the bore 970 by
34 means of the assembly 900.

35

1 The motor 902 would drive the traction stabiliser 908
2 which would "walk" along the pipe or conduit 970. The
3 dominating stabilizer 930 would be configured to drag
4 the cable 960 behind it as the assembly 900 rotated and
5 moved along the pipe 970. To obviate the difficulties
6 encountered at a bend in the pipe 970 it is envisaged
7 that the pipe tug assembly 900 would have a universal
8 coupling 980 (eg a Hooke joint) between the motor 902
9 and the traction stabiliser 908, thereby enabling the
10 assembly 900 to negotiate bends until limited by radii
11 smaller than the longest section length of the pipe tug
12 assembly 900.

13

14 It is also preferred that the aforementioned mechanism
15 to reverse the helix angle of the tractive elements 908
16 and 930 is included in the assembly 900. This would
17 enable the traction stabilizer to "walk" out of the
18 pipe for the same given rotation.

19

20 Figs 12 - 14 show a downhole drilling assembly 1000
21 essentially similar to the downhole assembly 80 of Fig.
22 10, but in more detail and somewhat less schematically.
23 Parts of the assembly 1000 which directly correspond to
24 parts of the assembly 800 are given the same reference
25 numerals, but with the leading "8" replaced by "10"
26 (eg, in Fig. 14, the motor which is equivalent to the
27 motor 802 of Fig. 10 is denoted "1002"). For a
28 detailed description of the parts of the assembly 1000
29 and their operation, reference should be made to the
30 foregoing description of the equivalent parts of the
31 assembly 800 and their operation.

32

33 Fig. 12 is an elevational view of either one of the
34 mutually identical downhole tools or traction
35 stabilizers 1008 and 1012, while Fig. 13 is a plan view

1 from above of the traction stabilisers 1008, 1012 (ie a
2 view from the left in Fig. 14 wherein the assembly 1000
3 is oppositely oriented to the assembly 800 as depicted
4 in Fig. 10). Fig. 14 is an elevation of the assembly
5 1000 drilling through geological material 1099 (in a
6 direction from left to right as viewed in Fig. 14).
7 Operation of the assembly 1000 and of its constituent
8 parts is as previously described in respect of the
9 assembly 800 (Fig. 10).

10

11 Figs 15 and 16 illustrate a downhole tool which is a
12 variation on the previously described downhole tools.
13 Fig. 15 is a longitudinal elevation of the outline of
14 the tool 1100 in an operational position within the
15 tubular casing 1190, while Fig. 16 is a longitudinal
16 section of the tool 1100 taken on a plane which is
17 vertical to the centre line of Fig. 15, and viewed in a
18 direction which is right to left in Fig. 15.

19

20 In the previously described downhole tools, the rollers
21 or other rolling elements had individual diameters
22 which were small relative to the overall peripheral
23 diameter of the tool. However, the tool 1100 differs
24 in that the rolling elements (detailed below) have
25 individual diameters which are more nearly equal to
26 (though still less than) the overall peripheral
27 diameter of the tool.

28

29 Referring specifically to Fig. 16, the tool 1100
30 comprises a tubular central member 1102 upon which are
31 mounted two spaced-apart single-row ball bearings 1104
32 and 1106 each fitted with respective toughened tyre
33 1108, 1110 formed of metal, polymer, or any other
34 suitable material.

35

1 Each of the bearings 1104 and 1106 is mounted on a
2 respective tilt bearing 1112 and 1114 whose mutually
3 parallel rotational axes are each diametrically aligned
4 with respect to the longitudinal axis of the central
5 member 1102. The bearing 1104 and 1106 are coupled by
6 means (not shown) for controllable conjoint tilting in
7 parallel planes about their respective tilt bearings
8 1112, 1114 such that each of the bearings 1104, 1106
9 rotates about a respective axis which is angularly
10 skewed with respect to the longitudinal axis of the
11 central member 1102. These rotation axes of the
12 bearings 1104 and 1106 are also laterally offset from
13 the longitudinal axis, in a direction which is upwards
14 from the plane of Fig. 16, and rightwards in Fig. 15.

15
16 Between the mutually longitudinally spaced-apart
17 bearings 1104 and 1106, the central member 1102 mounts
18 a cluster of three mutually coaxial bearings 1116,
19 1118, and 1120 each dimensionally identical to the
20 bearings 1104 & 1106, and each likewise being fitted
21 with a respective toughened tyre. Each of the ball
22 bearing 1116, 1118 and 1120 rotates about the same
23 rotation axis which is parallel to the longitudinal
24 axis of the central member 1102 (ie rotation axis is
25 non-skewed), and laterally offset equally and
26 oppositely to the lateral offset of the rotation axes
27 of the bearings 1104 and 1106, ie the common rotation
28 axis of the bearings 1116, 1118, and 1120 is displaced
29 in a direction which is downwards from the plane of
30 Fig. 16, and leftwards in Fig. 15.

31
32 Thus the bearing pair 1104, 1106, and the bearing
33 triplet 1116-1120 contact mutually opposite sides of
34 the casing 1190, as most clearly shown in Fig. 15, thus
35 to provide mutually opposed radial forces causing these

1 bearing groups each to bear against the inner face of
2 the casing 1190. The skew angle of the bearing pair
3 1104 and 1106 results in a longitudinal force being
4 developed as the tool 1100 rotates within the casing
5 1190, this longitudinal force being directed upwards as
6 viewed in Figs 15 and 16 when the direction of rotation
7 is clockwise as viewed from above and looking
8 downwards.

9
10 Fig. 17 is a perspective view of a downhole tool 1200
11 based on the "large roller" principle described above
12 with reference to Figs 15 and 16. In the tool 1200, a
13 central tubular member 1202 rotatably mounts upper and
14 lower rollers 1204 and 1206 on respective rotation axes
15 which are angularly skewed with respect to and
16 laterally offset from the longitudinal axis of the tool
17 1200, as described above in respect of the rollers 1104
18 and 1106 in the downhole tool 1100 of Figs 15 and 16.
19 The central member 1202 also rotatably mounts a central
20 roller 1208 on a respective rotation axis which is
21 laterally offset from the longitudinal axis of the tool
22 1200 by an amount equal to and in a direction opposite
23 to the lateral offset of the rotation axes of the upper
24 and lower rollers 1204 and 1206. The rotation axis of
25 the central roller 1208 may be parallel to the
26 longitudinal axis, or it may be skewed to match the
27 skew of the rotation axes of the upper and lower
28 rollers 1204 and 1206. Means (not shown) may be
29 incorporated into the tool 1200 to cause the rollers
30 1204, 1206, and 1208 to be mechanically and/or
31 hydraulically urged radially outwards in a controlled
32 or uncontrolled manner against the bore of the casing
33 or other tubular cavity within which the tool 1200 is
34 being operated. Further means (not shown) may be
35 incorporated into the tool 1200 for controllably

1 varying the skew angles of the rollers. The rollers
2 1204, 1206 and 1208 preferably incorporate peripheral
3 inserts 1210 of a hard wear-resistant material (eg
4 tungsten carbide), the rollers thereby superficially
5 resembling 'slices' of a conventional hard-faced
6 fixed-blade stabiliser.

7
8 Figs 18 and 19 are respectively a schematic elevation
9 and an end view illustrating a developed form of a
10 "large roller" downhole tool based on the above
11 described principles. In the downhole tool 1300 as
12 schematically depicted in Fig. 18, a longitudinally
13 extending central member 1302 mounts six large diameter
14 rollers 1304, 1306, 1308, 1310, 1312, and 1314 at
15 spaced-apart locations along the central member 1302.
16 Each of the rollers 1304-1314 has a respective rotation
17 axis which is both laterally offset and angularly
18 skewed with respect to the longitudinal axis of the
19 central member 1302, ie the centre line of the tool
20 1300, as depicted in Fig. 19. As shown in Fig. 18, the
21 rollers 1304-1314 have equal increments of mutual
22 angular displacement of their respective lateral
23 offsets, but this is not actually essential, the
24 requirement being that the lateral offsets be angularly
25 distributed in the tool as a whole such as to provide a
26 net balance of radial forces, ie such that a force in
27 any one radial direction is balanced by a diametrically
28 opposed radial force (or resultant of two or more
29 radial forces).

30
31 Each of the rollers 1304-1314 contacts the surrounding
32 casing 1390 at a respective point of contact (labelled
33 "1" - "6" in Fig. 18) at which the circumference of the
34 respective roller makes a small angle (equal to the
35 skew angle) with respect to a purely circumferential

1 direction around the bore of the casing 1390 at that
2 point, such that if the tool 1300 rolled around inside
3 the casing 1390 without slipping, these points of
4 contact would trace out paths equivalent to a screw-
5 thread around and along the base of the casing. Thus
6 at the same time as the tool 1300 provides rotational
7 support for a downhole assembly of which it forms part,
8 rotation of the tool 1300 tends to develop a
9 longitudinal force driving the tool along the casing.

10

11 Fig. 20 (elevation) and Fig. 21 (plan) schematically
12 depict a downhole tool 1400 which is a modification of
13 the tool 1300 described above with reference to Figs 18
14 and 19. In Figs 20 and 21, these parts of the modified
15 tool 1400, which are equivalent or analogous to parts
16 of the tool 1300 are given the same reference numerals,
17 but with the leading "13" replaced by a "14"; for a
18 description of any part of the tool 1400 not detailed
19 below, reference should be made to the relevant part of
20 the preceding description of the tool 1300.

21

22 In the tool 1400, the central roller-mounting 1402 has
23 the general form of a helix, each of the rollers
24 1404-1414 being centrally mounted on the helical member
25 1402 such that the required combination of lateral
26 offset and skew angle for each of the rollers 1404-1414
27 is provided by the helical displacement of the member
28 1402 from the longitudinal axis of the tool 1400,
29 rather than by offsetting the individual mounting of
30 each roller as in the Fig. 19 arrangement. The tool
31 1400 functions in the same manner as does the tool
32 1300.

33

34 While certain modifications and variations of the
35 invention have been described above, the invention is

1 not restricted thereto, and other modifications and
2 variations can be adopted without departing from the
3 scope of the invention as defined in the appended
4 Claims.
5

1 CLAIMS

2

3 1. A downhole tool for providing radial support for a
4 rotatable downhole assembly within a previously drilled
5 hole of substantially uniform diameter, said tool
6 comprising a central member constructed or adapted to
7 be incorporated in a rotatable downhole assembly for
8 rotation therewith in use of said tool, said central
9 member mounting a plurality of rolling element means in
10 respective positions which are circumferentially
11 distributed around said tool, each said rolling element
12 means being rotatably mounted on a respective axis
13 which is tangential to a notional helix substantially
14 coaxial with the longitudinal axis of said tool about
15 which said tool rotates in use of said tool such that
16 each said respective axis of said rolling element means
17 is skewed with respect to said longitudinal axis, each
18 said rolling element means having a respective
19 periphery which extends to the radially outermost
20 periphery of said tool whereby the radially outermost
21 periphery of said tool provides rolling radial support
22 for said rotatable downhole assembly in use of said
23 tool by means of the peripheries of said rolling
24 element means and the rotation of said rolling element
25 means about their skewed axes translates rotation of
26 said tool in use thereof to a longitudinally-directed
27 force acting through said central member on said
28 downhole assembly.

29

30 2. A downhole tool as claimed in Claim 1 wherein said
31 rotatable downhole assembly is a drillstring and said
32 notional helix is contra-rotary with respect to the
33 combination of the normal or forward direction of
34 rotation of the drillstring and the direction from said
35 tool towards a drill bit at the downhole end of the

1 drillstring, whereby normal or forward rotation of said
2 drillstring and of the tool incorporated therein
3 results in a longitudinal force tending to propel the
4 drillstring towards the blind end of the bore and
5 ultimately tending to force the drill bit into the
6 geological material to be drilled.

7
8 3. A downhole tool as claimed in Claim 2 wherein said
9 normal or forward direction of rotation of the
10 drillstring is clockwise as viewed from the surface and
11 looking down into the bore and said notional helix
12 progresses anti-clockwise in a downhole direction
13 therealong whereby the peripheries of said rolling
14 element means, where they extend to the radially
15 outermost periphery of the tool, align with a notional
16 right-hand thread around the outer periphery of said
17 tool.

18
19 4. A downhole tool as claimed in any preceding Claim,
20 wherein each respective axis of said rolling element
21 means is skewed with respect to the longitudinal axis
22 of the tool at an angle in the range from a very low
23 (but non-zero) angle, up to 45°, and more preferably at
24 an angle in the range from 0.5 to 15°.

25
26 5. A downhole tool as claimed in any preceding Claim,
27 wherein said downhole tool incorporates skew angle
28 variation means operable to make the skew angle
29 controllably variable.

30
31 6. A downhole tool as claimed in Claim 5, wherein
32 said skew angle variation means is capable of reversing
33 the hand of said notional helix whereby the direction
34 of the longitudinal force is reversed without reversing
35 the direction of rotation.

- 1 7. A downhole tool as claimed in any preceding Claim,
2 wherein said rolling element means are rollers, and the
3 peripheries of said rollers are individually
4 cylindrical or crowned.
5
- 6 8. A downhole tool as claimed in any preceding Claim,
7 wherein said rollers are individually mounted on a
8 respective axis.
9
- 10 9. A downhole tool as claimed in Claim 7, wherein
11 said rollers are mounted in coaxial groups, such that
12 within a group of rollers, individual rollers of that
13 group are capable of rotating at mutually differing
14 rotational rates.
15
- 16 10. A downhole tool as claimed in any preceding Claim,
17 wherein radial force applying means are incorporated in
18 the tool for applying radially outwardly directed
19 radial forces to the rolling element means to increase
20 their traction on the bore.
21
- 22 11. A downhole tool as claimed in Claim 10 wherein the
23 radial force applying means is such that the radially
24 outwardly directed radial forces applied to the rolling
25 element means are controllably variable.
26
- 27 12. A rotatable downhole assembly for rotatable
28 operation within a previously drilled hole of
29 substantially uniform diameter, said downhole assembly
30 comprising a downhole motor having a motor housing and
31 a rotatable motor output shaft coupled to a rotatable
32 motor output utilisation means, said downhole assembly
33 further comprising at least one downhole tool as
34 claimed in any preceding Claim, said at least one
35 downhole tool being coupled between said rotatable

1 motor output shaft and said rotatable motor output
2 utilisation means for rotation therewith in operation
3 of said assembly to provide radial support therefor and
4 to translate such rotation to a longitudinally-directed
5 force acting through said motor output utilisation
6 means.

7

8 13. A downhole assembly as claimed in Claim 12,
9 wherein said downhole assembly comprises a plurality of
10 such downhole tools, each as claimed in any of Claims
11 1-11, and each being coupled between said rotatable
12 motor output shaft and said rotatable motor output
13 utilisation means.

14

15 14. A downhole assembly as claimed in Claim 12 or
16 Claim 13, wherein said rotatable motor output
17 utilisation means comprises a drill bit, said at least
18 one downhole tool comprised in said downhole assembly
19 being formed dynamically to increase the effective
20 weight-on-bit during normally directed rotation of said
21 drill bit by said downhole motor.

22

23 15. A downhole assembly as claimed in any of Claims
24 12-14, wherein said motor housing is coupled to
25 countertorque means for reacting motor torque output by
26 said motor output shaft, said countertorque means
27 rotationally constraining said motor housing with
28 respect to said previously drilled hole.

29

30 16. A downhole assembly as claimed in Claim 15,
31 wherein said countertorque means provides a rotational
32 braking effect while allowing relative freedom of
33 movement in a longitudinal direction.

34

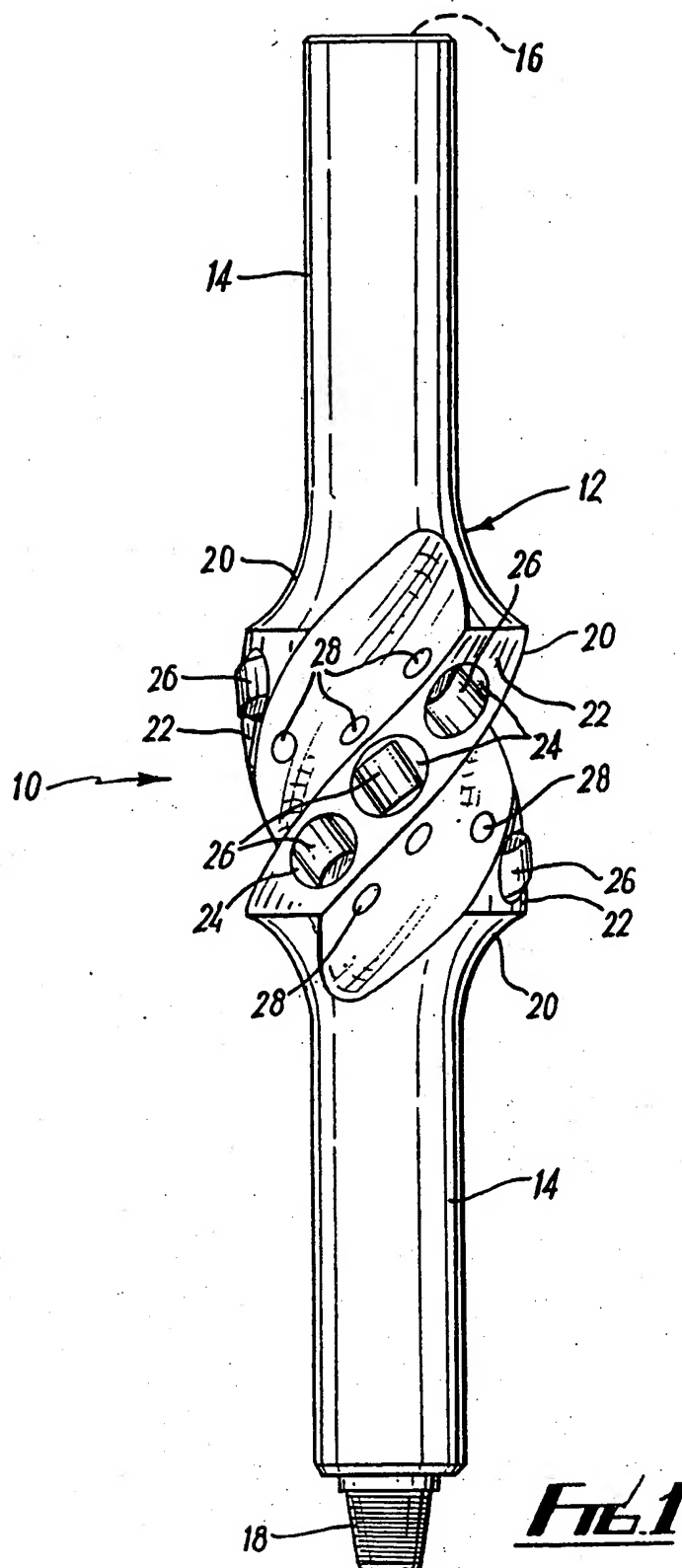
35 17. A downhole assembly as claimed in Claim 16,

1 wherein said rotational braking effect is provided by
2 forming said countertorque means with a peripheral
3 array of hole-contacting rotatable rollers having their
4 axes of rotation substantially tangential to notional
5 circles substantially coaxial with the longitudinal
6 axis of said downhole assembly.

7
8 18. A downhole assembly as claimed in Claim 16,
9 wherein said countertorque means comprises a further
10 downhole tool as claimed in any of Claims 1-11, the
11 notional helix of said further downhole tool being
12 oppositely handed with respect to the notional helix of
13 said at least one downhole tool coupled between said
14 rotatable motor output shaft and said rotatable motor
15 output utilisation means whereby relative
16 contrarotation of said motor housing with respect to
17 said motor output shaft results in commonly directed
18 longitudinal forces at said at least one and further
19 downhole tools comprised in said downhole assembly.

20
21 19. A downhole assembly as claimed in any of Claims
22 12-18, wherein the motor of said downhole assembly is a
23 hydraulic motor supplied in operation thereof with
24 pressurised fluid by way of tubing which may be
25 flexible, said downhole assembly being coupled to said
26 tubing by way of a swivel coupling which is
27 substantially fluid-tight.

28
29 20. A downhole assembly as claimed in any of Claims
30 12-19, wherein said downhole assembly has major
31 components and sub-assemblies thereof longitudinally
32 coupled by one or more couplings transmissive of torque
33 and longitudinal forces but yieldable about axes
34 transverse to the longitudinal axis whereby the
35 downhole assembly may conform to bent holes.



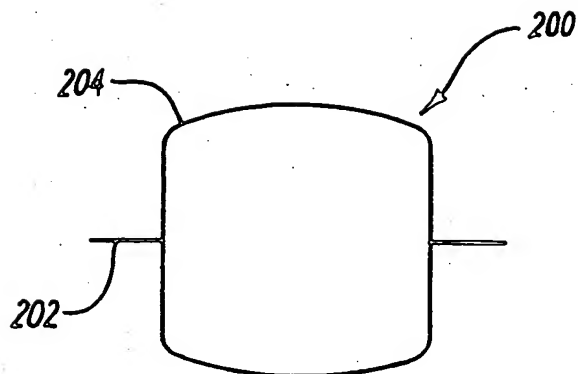


FIG. 2

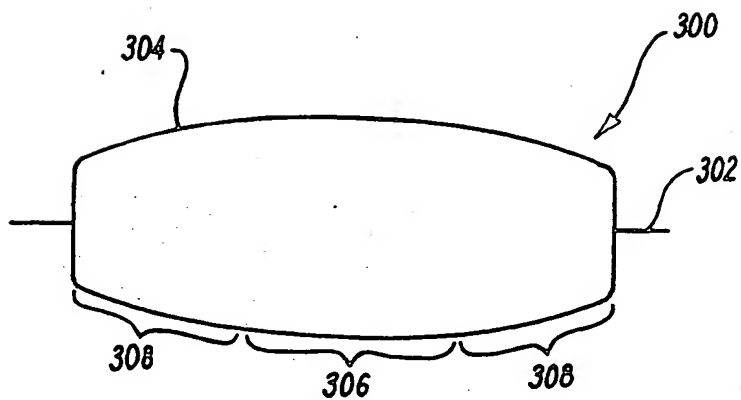


FIG. 3

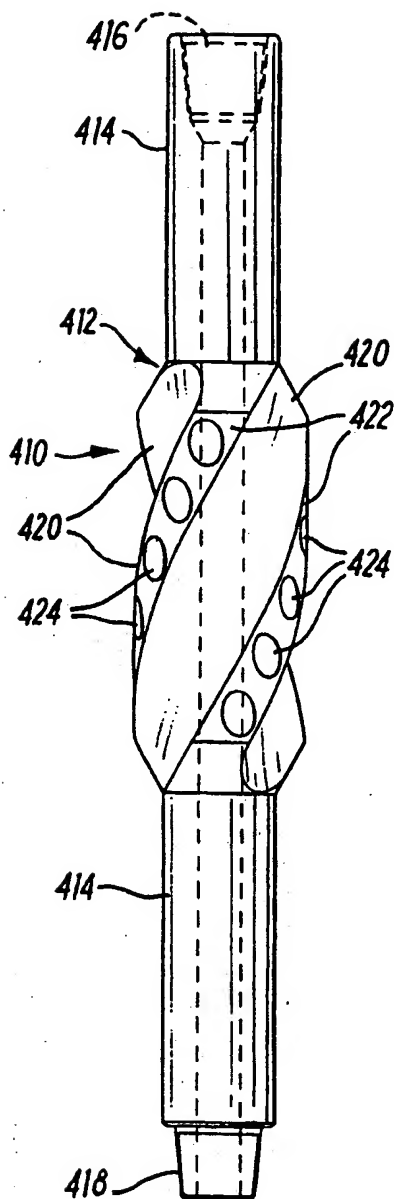


FIG. 4

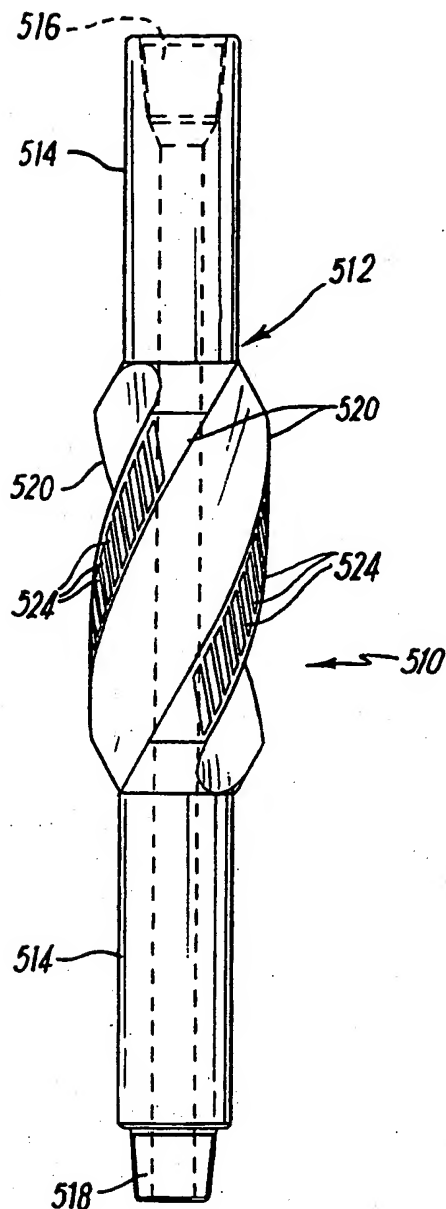


FIG. 6

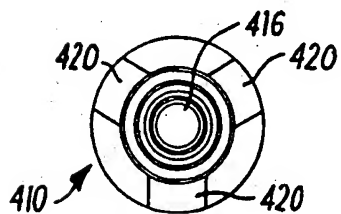


FIG. 5

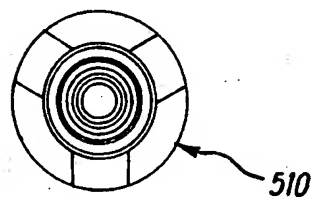
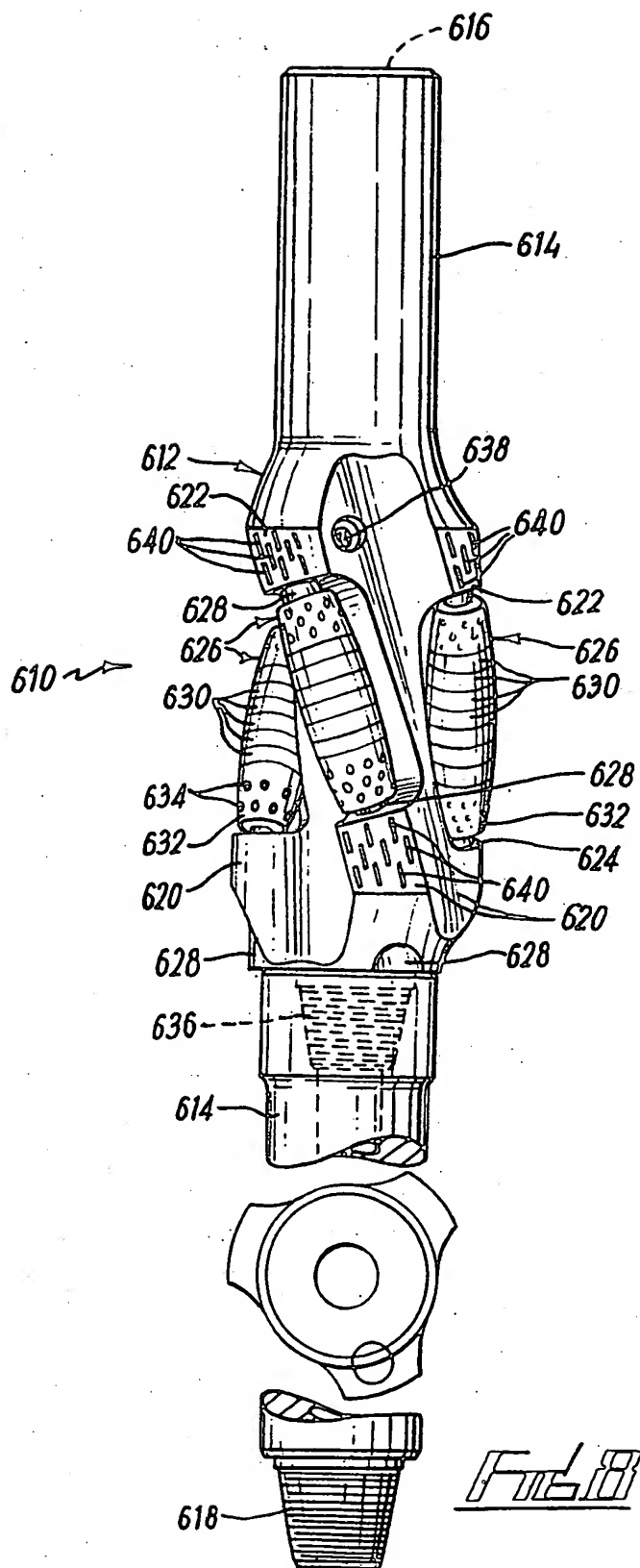


FIG. 7



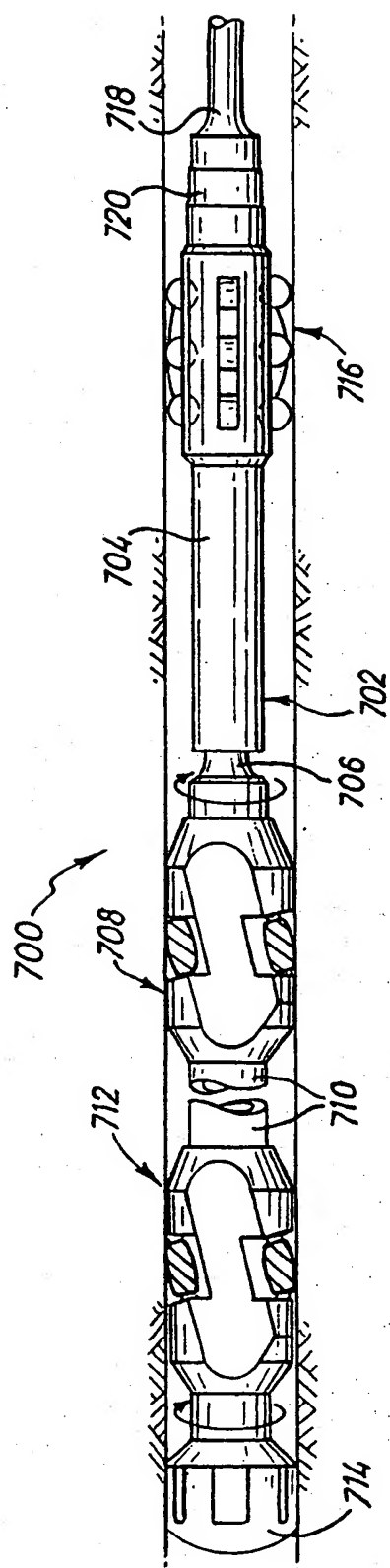


FIG 9

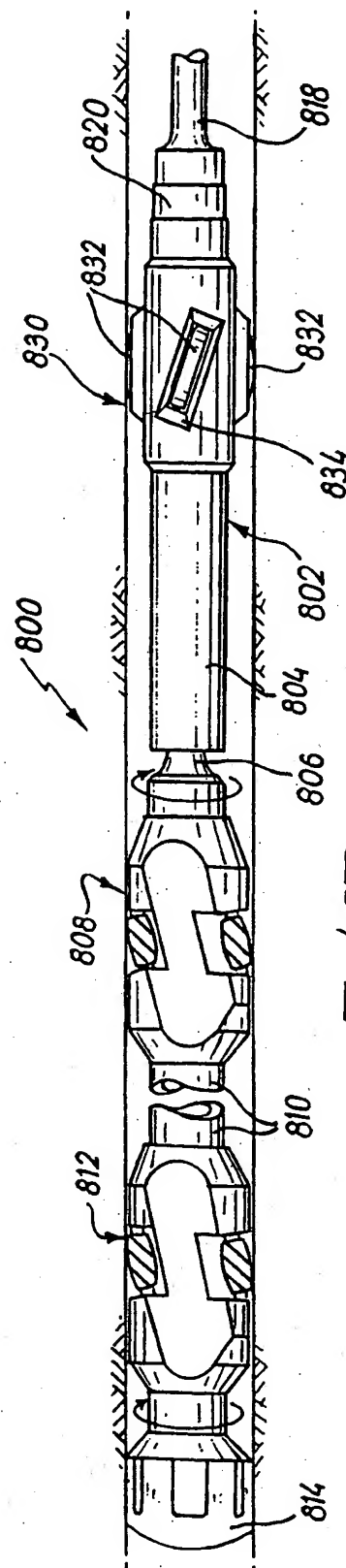


FIG 10

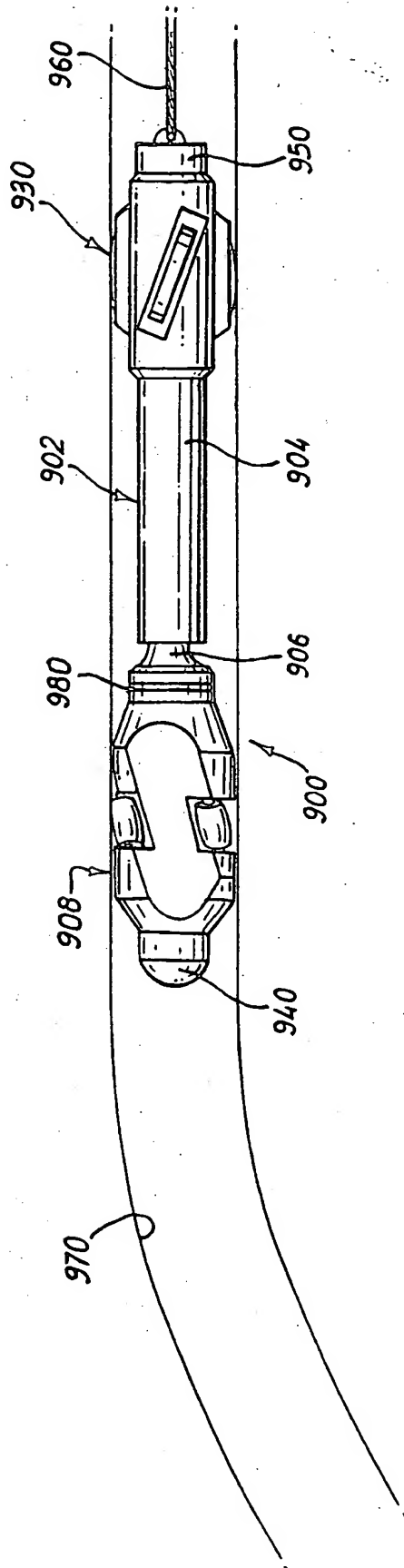


Fig. 11

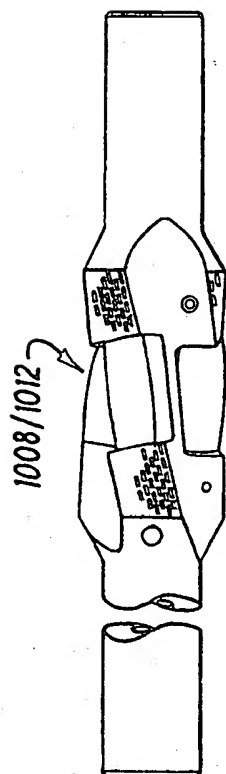


Fig. 12

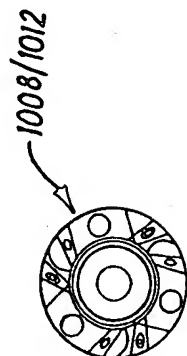


Fig. 13

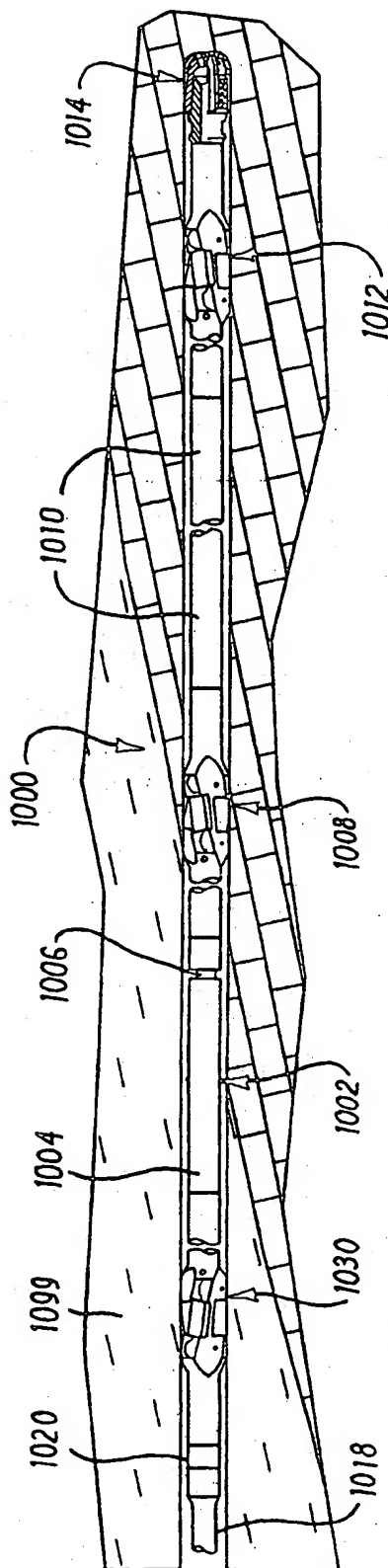


Fig. 14

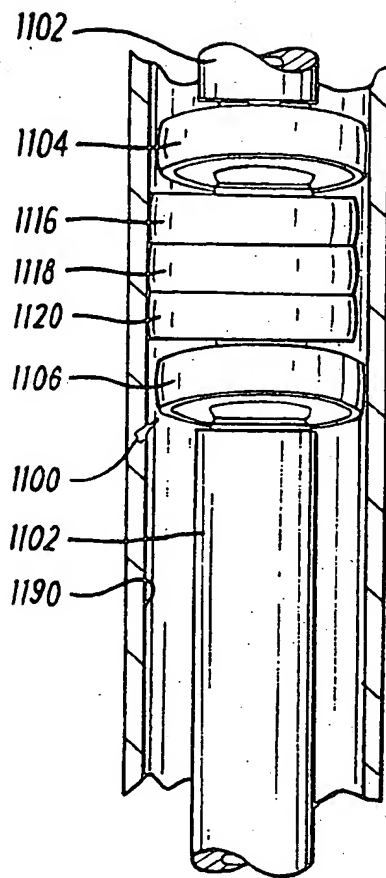


FIG. 15

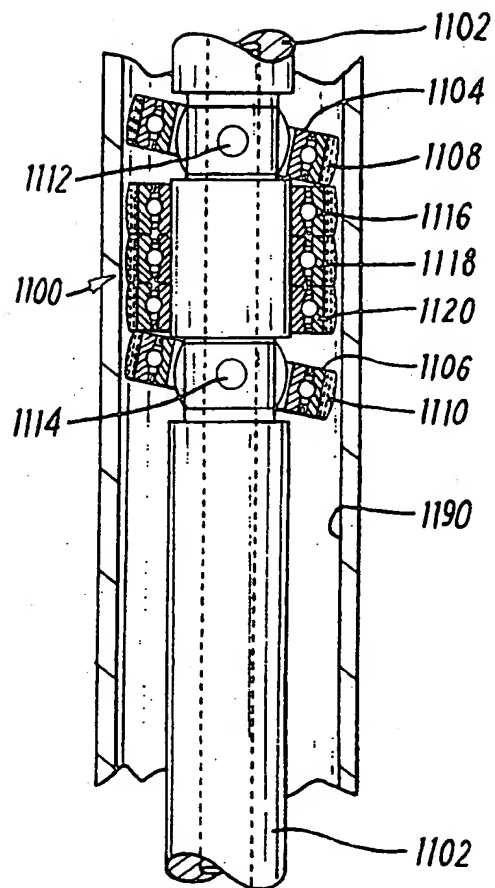


FIG. 16

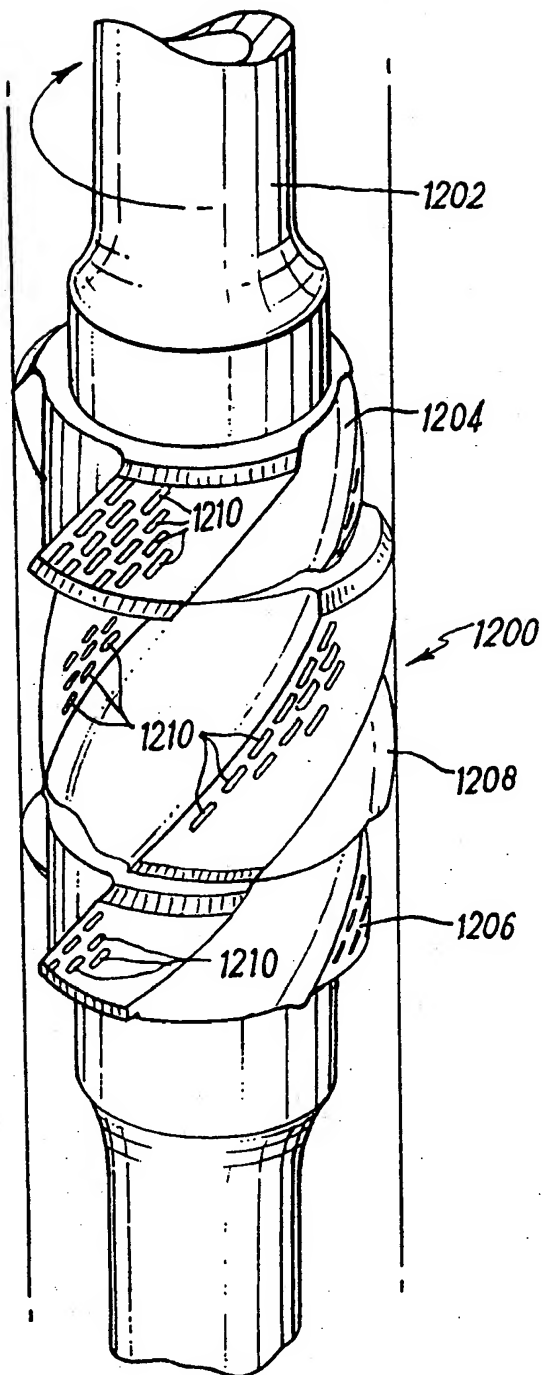


FIG. 17

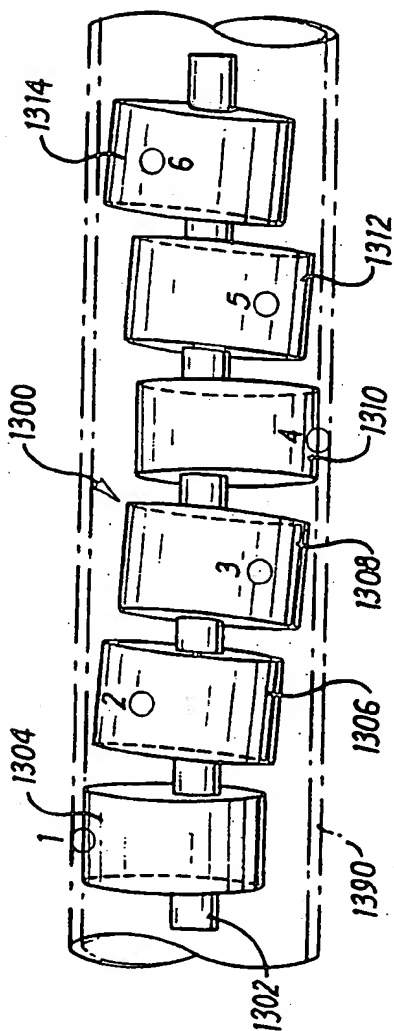


Fig. 18

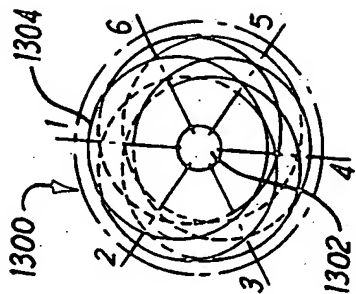


Fig. 19

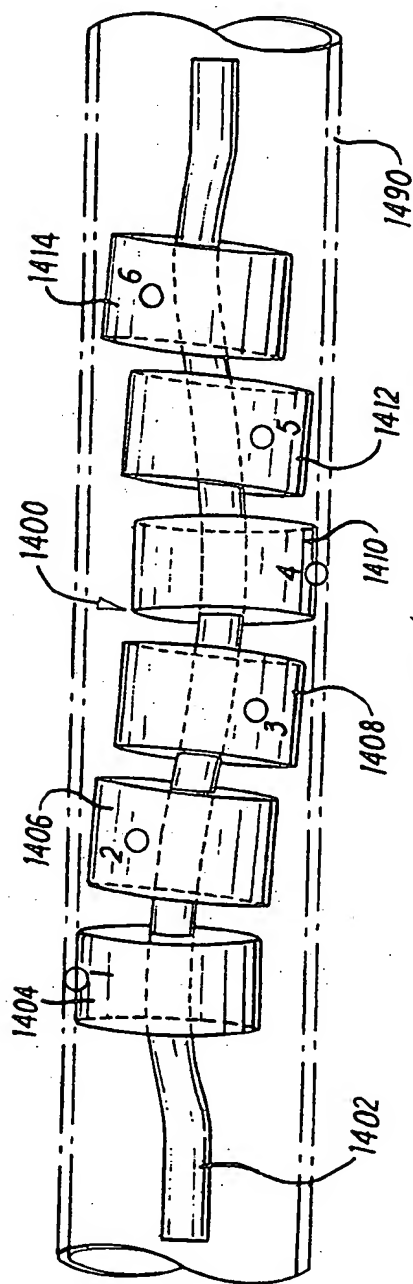


Fig. 20

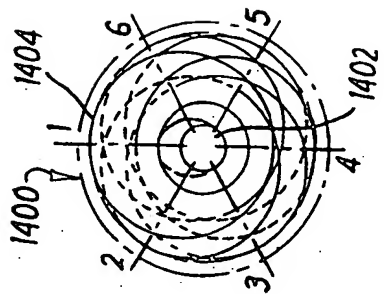


Fig. 21

INTERNATIONAL SEARCH REPORT

International application No.

PCT/GB 93/01114

A. CLASSIFICATION OF SUBJECT MATTER

IPC5: E21B 17/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC5: E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 4365678 (J.L. FITCH), 28 December 1982 (28.12.82), column 1; column 3, line 11 - line 27 --	1,7,12-14, 19-20
A	EP, A1, 0333450 (ANDERSON, C.A.), 20 Sept 1989 (20.09.89) -----	1-20

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

13 Sept 1993

Date of mailing of the international search report

29.09.93

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Authorized officer

Christer Bäcknert

SA 5326

INTERNATIONAL SEARCH REPORT
Information on patent family members

26/08/93

International application No.

PCT/GB 93/01114

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4365678	28/12/82	US-A- 4465146	14/08/84
EP-A1- 0333450	20/09/89	US-A- 4958692	25/09/90

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